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4.3 MICROMETER LASER DEMONSTRATION EXPERIMENT

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA 90230

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The possibility of converting multiline cw DF chemical laser radiation to single line cw 4.3 micrometer radiation by means of an Optical Resonance pumped Transfer Laser (ORTL) is investigated. The ORTL medium consists of a DF and CO_2 mixture and a suitable diluent. The optically pumped DF collisionally transfers its vibrational excitation to the CO_2. This program is concerned with a demonstration of 4.3 μm (micrometers) oscillation between the (00^01) and ground state CO_2 levels. A laser demonstration was performed → next page

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20. ABSTRACT (Continued)

and is described here. ORTL radiation was observed at the wavelength corresponding to the transition of interest. New laser transitions emanating from optically pumped DF molecules were also observed; one of these transitions overlaps the CO_2 transition of interest. Factors leading to the conclusion that CO_2 ORTL oscillation between the (00^01) level and the ground state was observed are discussed.

deg

SUMMARY

Theoretical Analysis indicated the possibility of exciting "two-level" 4.3 μm cw laser action involving the CO_2 $(00^01) \rightarrow (00^00)$ transition using high intensity DF laser power as an optical pump. The necessary very large population inversion in CO_2 was postulated to be achievable in a CO_2/DF/He gas mixture where primary DF pump power was to be used for generating vigorous excitation of DF molecules via multiline DF optical resonance absorption. The excitation thus achieved in the DF molecules was predicted to be transferred to the CO_2 (00^01) level with nearly unit efficiency, generating extraordinarily high population levels required in the CO_2 acceptor state. The goal of this program was to experimentally verify this postulated laser transition.

Laser demonstration experiments were conducted and oscillation at 4.3 micrometers was observed. The Optical Resonance pumped Transfer Laser (ORTL) cell containing DF and CO_2 was located internal to the DF pump laser optical resonator. The chosen ORTL gas mixture was maintained at 22 Torr and contained mole fractions of 6.5, 25, and 68.5 percent for CO_2 DF, and He respectively. The 4.3 μm resonator was a closed cavity configuration. Laser action was determined by observation of the scattered light from one of the resonator mirrors. Laser radiation between 4.25 and 4.29 micrometers was observed and identified with the $(00^01) \rightarrow (00^00)$ P-transitions P(2) through P(20). In addition, new DF laser transitions, as well as some previously observed DF lines, were observed in the ORTL cell. The unexpected occurrence of strong DF laser oscillation in the wavelength region of interest for CO_2, complicates the problem of unique laser transition assignment. The assignment to CO_2 was therefore made on the basis of additional spectral structure information.

PREFACE

The work discussed in this report is based upon propritary prior work supported by Hughes Independent Research and Development funds. In addition, work supported by the Ballistic Missile Defense Advanced Technology Center under Contract DASG60-77-C-0056 has strongly influenced the technical approach on the present program. It has also made possible the demonstration of two level laser action on the CO_2 $(00^{\circ}) \rightarrow (00^{\circ}0)$ transition reported here. This task could never have been accomplished in a five month time span without the extensive use of apparatus that was available from prior efforts covered by the BMDATC contract dealing with a related, but separate, technology. This report was authored by J. Finzi and P.K. Baily. The authors would like to acknowledge the technical guidance provided by F.N. Mastrup, and numerous technical discussions with G. Holleman and J. Wang. We would also like to acknowledge the assistance of H. Injeyan, J. Jacobson, C. Lovejoy, L. Marabella, R. Shimazu, and L. Williams in performing the experiments.

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1. INTRODUCTION

1.1 BACKGROUND

High energy chemical lasers in advanced space systems are presently under active consideration by ARPA and other government agencies. The ability of the laser system to deliver near ultimate irradiance levels to distant targets at prescribed output power levels depends on the extracted beam quality, the output optics size and the attainable precision in pointing and tracking. Modern chemical space laser concepts involve cavity resonators, such as the cylindrical configuration, where satisfactory "mode" control or, more precisely, the ability of the resonator to outcouple a near diffraction limited beam is questionable or uncertain. Achievement of the required precision in pointing and tracking may require single line operation once adaptive optics approaches are seriously pursued for beam focusing. This is so because the active phase control of a selected line from amongst the large number of emitted high energy chemical laser lines does not imply control of the entire multiline beam. It is likely that successful active phase control of a chemical laser beam will only be possible when the output is in fact single line.

The related problems of beam control and single line operation are both amenable to solution by the Optical Resonance pumped Transfer Laser (ORTL) concept. The ORTL concept (Figure 1) promises to permit one to convert from high efficiency multiline, low optical quality, "multimode" cw primary laser cavity power to single line, cw low divergence laser output power. This is accomplished by arranging for the primary, multiline DF (HF) power to oscillate between too highly reflective mirrors as shown in Figure 1. The ORTL cell, which is placed within this trapped DF (HF) laser radiation field becomes, in a well designed ORTL, the major primary power sink. Effective resonance absorption in the ORTL cell is achieved by mixing a well balanced amount of DF (HF) gas into the ORTL gas. The multiline, primary DF (HF) laser power absorbed by the DF (HF) donors is subsequently transferred by V-V collisions to an acceptor molecule which becomes the lasing molecule for the single line output (ORTL) laser. Expectations of better beam quality are a consequence of the resonant absorption of optical radiation; this

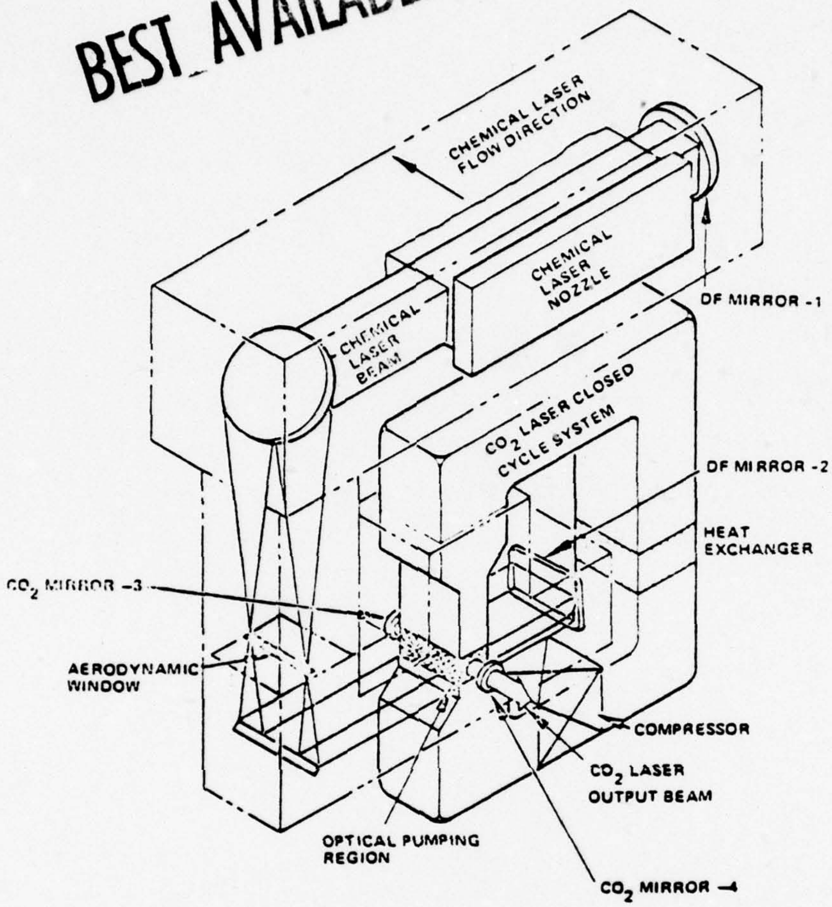

Figure 1. Optical Resonance Pumped Transfer Laser (ORTL) Concept.

minimizes the heating of the ORTL medium and good medium homogeneity can be maintained. This is especially true if the primary and ORTL radiation are very close in wavelength. In addition, very high volumetric Megawatt/ liter active volume) power output levels appear to be realizable. The closed cycle ORTL concept would allow the use of unusual gases as ORTL laser sources. These might include isotopically enriched substances or substances which should not be discharged into the atmosphere at high rates because of their explosive or toxic nature.

The intracavity ORTL concept was first demonstrated at Hughes in June, 1976* with a multiline DF laser as the primary source of radiation and CO_2 as the ORTL medium. Single line CW oscillation was achieved at 10.6 microns. This 10.6 μm or DF/CO_2 ORTL is not very practical for applications specifically requiring efficient space lasers, however, because of the inherent and unavoidable power loss associated with converting DF power at an average wavelength of 3.8 μm to 10.6 μm CO_2 laser radiation. This power loss occurs because all energy transfer processes in the ORTL medium are quantum effects and, therefore, the maximum possible ORTL output power to ORTL input power ratio is limited by the wavelength ratio. Another ORTL with a more favorable, i.e., shorter, output wavelength was therefore desired. In the special case of DF/CO_2 ORTL's very reliable predictions on the transfer of DF excitation to the CO_2 (00^01) level could be made because of the detailed and quantitative knowledge of the involved kinetics. Such analysis indicated that mixing ratios and pressures could be defined where over 90 percent of the optically pumped DF level energy would be transferred to the CO_2 (00^01) level. Shorter wavelength lasing could be accomplished if it were possible to enforce effective lasing from CO_2 (00^01) to a level close to the ground state or to the ground state itself. Further theoretical work at Hughes clearly indicated the possibility of effective lasing in the CO_2 4.3 μm band with a multiline DF to single line 4.3 μm power conversion efficiency as high as 70 percent. The only uncertainty was the unknown role of V-V collisions in the CO_2 ORTL component.

The high efficiencies potentially achievable in this "two-level" system lead to a preliminary investigation of the scalability of such a laser system. Under the sponsorship of Hughes IR&D, a first order model was developed that described the complicated interaction of the multiline pump (DF) laser and the ORTL both situated in the same trapped DF radiation field. The relevant DF and CO_2 vibrational energy level structure is shown in Figure 2. For favorable conditions, power conversion efficiencies from 3.8 μm average wavelength, multiline DF chemical laser pump power to single line ORTL output power at 4.3 μm

*J.H.S. Wang, J. Finzi, and F.N. Mastrup, Appl. Phys. Lett. 31, 35 (1977)

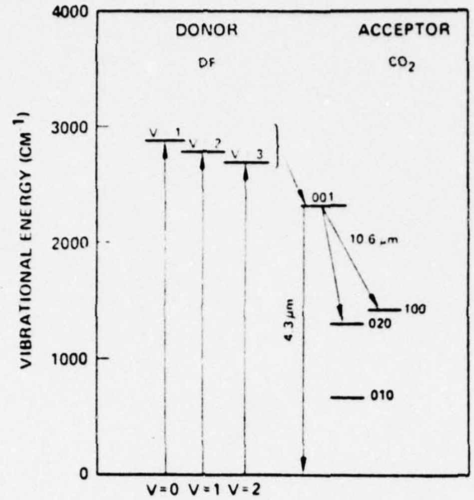

Figure 2. DF/CO_2 energy transfer level diagram.

are predicted to be over 70 percent. Calculated output power referred to unit volume can reach 1.7 megawatt/liter at room temperature with an optical pump flux of 90 kw/cm^2 at the ORTL cell. As a result of these considerations a five month program was undertaken to experimentally demonstrate a 4.3 micrometer DF/CO_2 Optically pumped Resonance Transfer Laser.

1.2 PROGRAM OBJECTIVES

The major objectives of the 4.3 Micrometer Laser Demonstration Experiment Program were to:

- Demonstrate and characterize 4.3 μm CO_2 lasing action in a DF laser pumped DF/CO_2 ORTL.
- Assess, through comparison with theoretical analysis, the gross effects of V-V collisions in this system.
- Define the need for future and refined work, if any, in this technology area as applied to the chemical space laser ORTL.

The major technical problem associated with a successful laser demonstration was the uncertain effects of $CO_2 - CO_2$ V-V collisions. To successfully

achieve the objectives the program was defined in terms of four work tasks as follows:

1. Apparatus Modification and Experimental Design
2. 4.3 Micrometer CW DF/CO_2 ORTL Demonstration
3. 4.3 Micrometer CW DF/CO_2 ORTL Characterization
4. Data Analysis and Evaluation

While the objectives associated with the first and second tasks were achieved, further experiments will be required to determine the precise role of V-V collisions.

1.3 ACCOMPLISHMENTS

The program plan which was delineated at the inception of the contract was followed with no major modifications. During the first three months of the program, the Hughes DF/CO_2 ORTL model was used to define favorable conditions for achieving inversion in the CO_2 $(00^o1) \rightarrow (00^o0)$ transition. Fluorescence experiments were performed under those conditions. The quantitative analysis of these data indicated that population inversions on this transition were probably achieved. These experiments were described in the Interim Technical Report (Hughes Report No. P77-490, October, 1977) and the reader is referred to that report for details. Also during the first three months the configuration and conditions for an intracavity laser demonstration experiment were defined. ORTL and DF resonator mirrors and an ORTL cell were fabricated.

While awaiting completion of this hardware, an extra-cavity 4.3 micrometer laser demonstration was attempted and transient oscillations were observed in the 4.1 to 4.7 μm band. The experiment was described in the October 1977 Monthly Report. The DF pump flux available in this configuration was fairly low (200 W/cm^2); nevertheless transient 4.3 μm laser emission signals were observed with a 3 cm gain length. However, the flow conditions could not be controlled well enough to allow reliable reproduction of the laser emission where inversion was barely achieved. This experiment will not be described again because it has been largely superseded by the

intracavity experiment which was carried out in the fifth month of the program. This configuration enabled a much larger pumping flux to be utilized and reliable cw operation was achieved. The experimental details are described in Section 2. The laser emission wavelength was measured with a spectrometer, and the observed radiation was at the expected wavelength. Unexpectedly, DF laser laser oscillation on a variety of high vibrational level transitions was also observed. Analysis of these additional transitions has led to an identification of a number of optically excited DF lines, some of them associated with v = 4 to v = 3 transitions. One of these, namely P(13), has not been observed before and overlaps the CO_2 $(00^01) \rightarrow (00^00)$ transition. The unexpected occurrence of this particular DF laser transition in the ORTL cell, of course, considerably complicates the problem of unequivocal identification. Additional evidence besides the match of wavelength with a likely CO_2 transition is therefore required for identification. Such additional evidence is available and is presented in the body of the report.

2. INTRACAVITY LASER DEMONSTRATION EXPERIMENT

2.1 EXPERIMENTAL CONFIGURATION

The facility used for intracavity 4.3 μm laser demonstration experiments has been described in detail elsewhere.* The discussion here will stress the operating characteristics of the facility as they pertain to the present experiments. A photograph of the intracavity ORTL facility is shown in Figure 3 and a schematic is shown in Figure 4. Referring to the schematic, M_1 and M_2 housings contain the mirrors that form the DF laser resonator cavity, while M_3 and ORTL house the CO_2 laser mirrors. The two optical axes are orthogonal.

The ORTL gas enters the ORTL block from below and flows into the ORTL chambers through a 3 mm circular duct (see Figure 5). Surrounding the duct is a gas curtain of helium that matches the pressure and velocity of the $DF/CO_2/He$ core flow. The helium curtain serves as a gas boundary to the ORTL flow, confining it to the duct cross section as it leaves the nozzle. The nozzle and curtain are shown in the foreground of Figure 3. The flow intersects both the DF and CO_2 laser axes 5 mm downstream of the nozzle. The flow exits on top through the vertical tube shown in the photograph.

The high circulating DF flux is focused to pump the ORTL cell by the DF optical resonator cavity. Two spherical mirrors 2" diameter, 71 cm radius, are separated by a distance of 141 cm to form a concentric cavity. The copper substrates are water cooled, and coated with Ag/ThF_4. They have a measured reflectivity of 99 ± 0.2 percent at 3.75 μm. The temperature rise of the cooling water is measured by thermocouples, enabling calorimetric measurement of the power deposited in each mirror. A CaF_2 window at Brewster's angle provides the necessary separation between the DF laser medium (~1 Torr) and ORTL medium (20-200 Torr).

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*Interim Technical Report, 4.3 Micrometer Demonstration Experiment, Hughes Report No. P77-490, October, 1977, Appendix A, and Monthly Report for July, Contract DASG60-77-C-0056, Optical Resonance Transfer Laser Investigation.

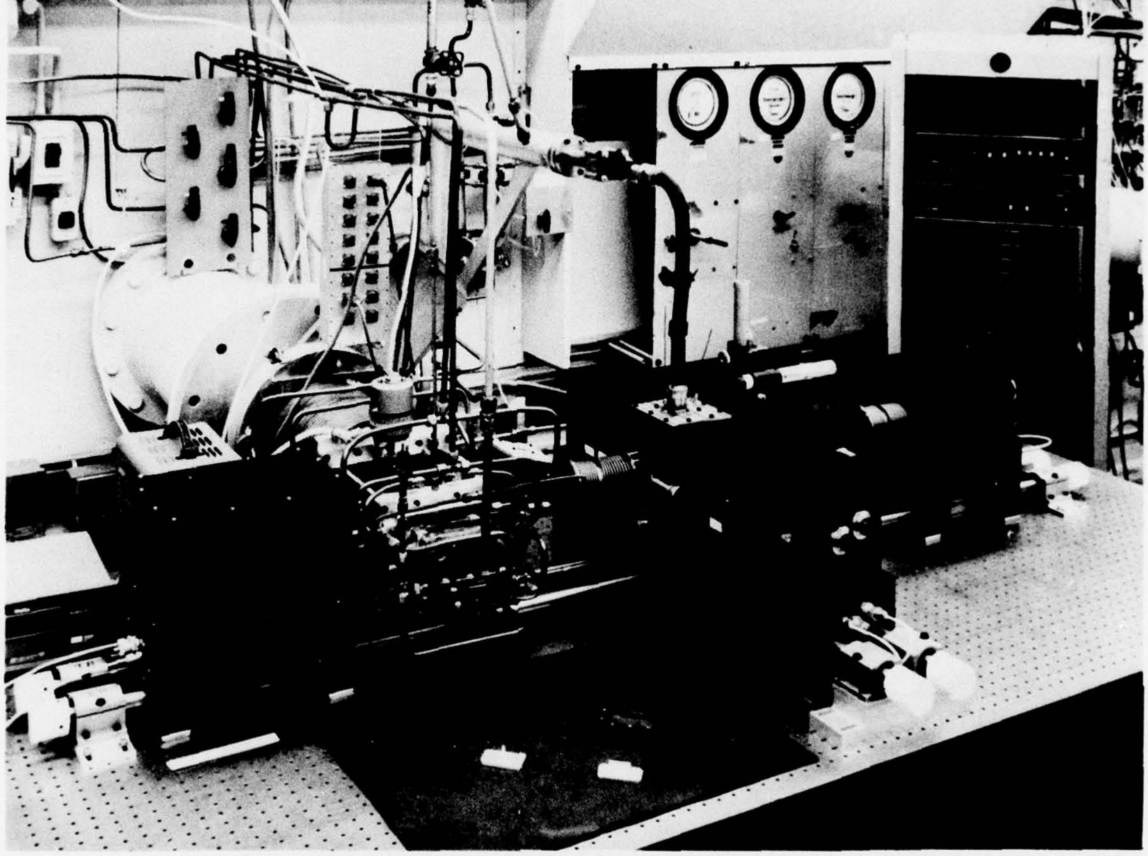

Figure 3. Intracavity ORTL Facility.

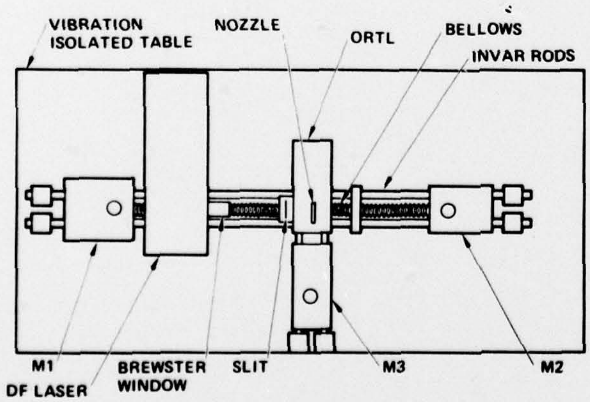

Figure 4. Intracavity ORTL Schematic.

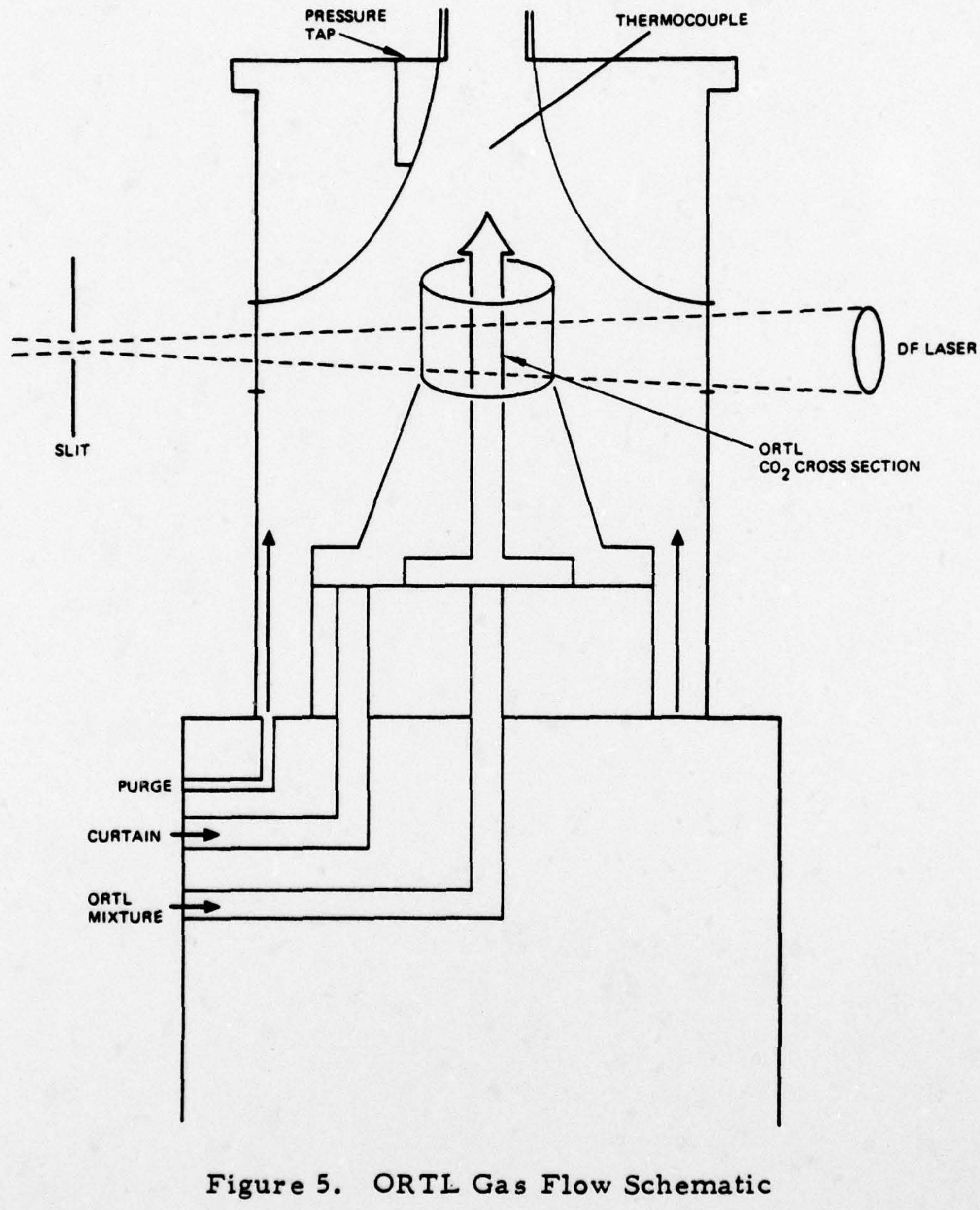

Figure 5. ORTL Gas Flow Schematic

The DF power outcoupled by the Brewster window easily burns plexiglas allowing measurement of the beam cross-section. The beam cross-section converges to a minimum at a 71 cm distance from M_1 (cavity center), then diverges. Plexiglass burns are routinely made at this distance and at a distance equivalent to the ORTL nozzle location (10 cm from cavity center) to provide information on the DF irradiation beam cross-section. The intracavity flux at the ORTL nozzle is then obtained from the relation:

$$F_N = \frac{Q_1}{(1 - R_1)A_N} + \frac{Q_2}{(1 - R_2)A_N}$$

where F_N is the intracavity flux at the nozzle, A_N is the beam cross section at the nozzle, and Q_1, Q_2, R_1, and R_2 represent the power deposited in mirrors one and two and their reflectivities. Typical values for Q_1 and Q_2 range from 60 to 75 watts, and $R_1 = R_2 \approx 99$ percent, and A_N is (4-5) mm x 2 mm. Thus F_N ranges from 120 to 190 kw/cm^2.

In addition to providing information about the beam cross section, the outcoupled DF beam is directed toward a spectrometer to record the spectral distribution. Approximately 30 percent of the output falls in the $1 \rightarrow 0$ band, 40 percent in the $2 \rightarrow 1$ band and 30 percent in the $3 \rightarrow 2$ band. The rotational distribution is similar for each band, ranging from P(8) to P(14) with the peak at P(10) or P(11). The rotational distribution is sensitive to the presence of DF in the ORTL gas. Because intracavity absorption, and therefore loss is a function of vibrational and rotational quantum number, one expects the intracavity flux distribution for differing V, J states to change. For the range of DF mixture examined the distribution shifted by one to two J lines toward higher J states.

Elements of the 4.3 μm laser demonstration experiment are shown schematically in Figure 6. The CO_2 resonator is formed by a flat mirror and a 1 meter radius concave mirror, both coated for 99.8 percent reflectivity at 4.3 μm and separated by 45 cm. (The reflectance of the optics was measured on a Perkin Elmer Model 180 spectrometer.) The cavity is nearly semiconfocal. The fundamental mode beam waist is 1.2 mm. A shutter supporting a 1 mm thick CaF_2 window can be interposed to either entirely block

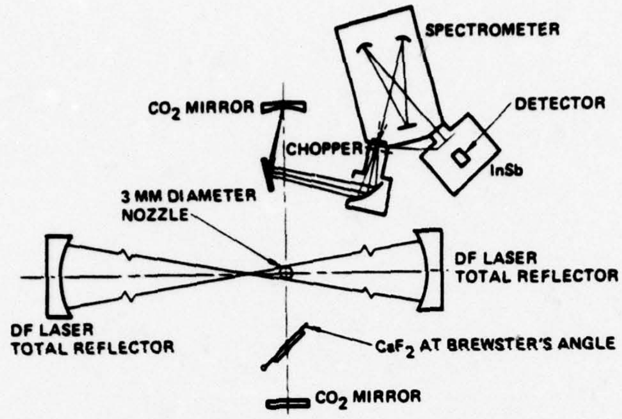

Figure 6. Laser Demonstration Apparatus.

the beam or place a CaF_2 window at Brewster's angle. Laser oscillation is detected by light scattered from the spherical mirror and then imaged onto either a radiometer or an evacuated spectrometer (McPhearson 218).

The radiometer contains a torodial mirror to focus the image onto a 0.050 inch diameter aperture. An interference filter (4.1 μm to 4.8 μm bandwidth) located immediately behind the aperture serves to discriminate 4.3 μm emission from DF laser scattered light and 10.6 μm oscillation. The signal is detected by a Hg:CdTe detector, then fed to a PAR 124 lock-in amplifier for signal-to-noise enhancement. The entire radiometer path length is rigorously purged with N_2 to allow unattenuated transmission of 4.3 μm band radiation.

Following a 4.3 μm experiment, the radiometer was calibrated "in situ" with a CO_2 laser. The flat mirror at M_3 was removed, and a 4 mm diameter CO_2 beam coincident with the 4.3 μm optic axis was injected. The CO_2 beam cross section at the scattering mirror was measured, as well as the beam power and the lock-in amplifier signal. The 10.6 μm signal was scaled to 4.3 μm taking into consideration detector responsivity, coating reflectivity, and scattering efficiency. The calibration factor thus estimated was 12 watts incident power on the mirror for each volt of the lock-in amplifier.

The ORTL turn-on procedure is as follows. First the ORTL N_2 purge, the curtain and the nozzle flows are established. At this point, the nozzle

flow contains only helium. The DF laser is turned on and aligned for maximum power. A scan is made of the DF laser spectrum, and the beam cross section at the ORTL nozzle is verified with a plexiglas burn. (It is essential that the length of the DF burn be 50 percent longer than the 3 mm ORTL nozzle, and that the DF and CO_2 axes intersect.) DF and CO_2 are then added to the He core flow, and the ORTL cavity pressure is set by throttling the flow. Addition of CO_2 last is a safety precaution to minimize the possibility of CO_2 penetration past the confines of the He curtain.

2.2 EXPERIMENTAL RESULTS

Two types of 4.3 μm laser demonstration experiments were carried out. The first series used a radiometer to detect stimulated emission, while in the second series the radiometer was replaced with a spectrometer in order to further define the emission wavelength. A sample of the strip chart data obtained for a successful 4.3 μm radiometer experiment is shown in Figure 7. The experimental conditions prevailing at the time the circle is indicated are given at the left. The mole fractions were: CO_2 5.1 percent, DF 17 percent, and He 78 percent, at 23 torr. The irradiation flux was 150 kw/cm^2. A summary of 4.3 μm experimental conditions is given in Table I. On the average, the ratio of DF to CO_2 is about 4 to 1. The temperatures listed in the table are measured 2 cm downstream of the excitation zone; they therefore indicate the total power absorbed by the gas, but not the instantaneous temperature at the excitation zone.

Results obtained when the radiometer was replaced by a spectrometer are shown in Figures 8 and 9. The experimental conditions are given in the last 3 rows of Table I. The spectrometer grating had 150 lines/mm and was blazed at 4 μm. Its dispersion was 212 A/mm.

2.3 DISCUSSION OF RESULTS

Figure 7 clearly indicates that stimulated emission occurred within the wavelength region of 4.1 μm to 4.8 μm. No signal was detected for a DF/He mixture, under these conditions. Rapid switching between 4.3 μm

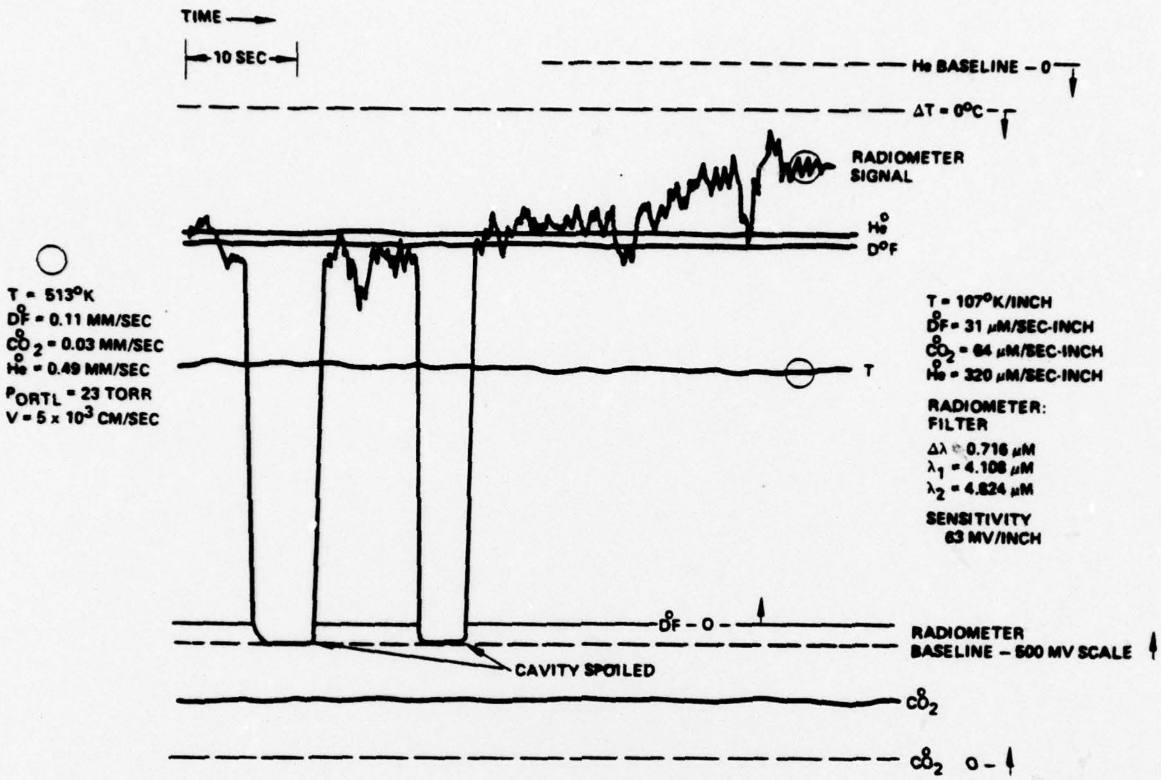

Figure 7. 4.3 μM Laser Demonstration.

TABLE I. INTRACAVITY LASER DEMONSTRATION EXPERIMENTS

Exp't	Flux (kw/cm^2)	CO_2 (%)	DF (%)	He (%)	P (torr)	T (°K)	Detection
1	73	6.7	29	64	22	>420	Radiometer
2	150	5.1	17	78	23	513	Radiometer
3	200	6.6	25	68	22	472	Spectrometer
4	230	6.9	25	68	22	498	Spectrometer
5	230	6.3	23	71	20	494	Spectrometer

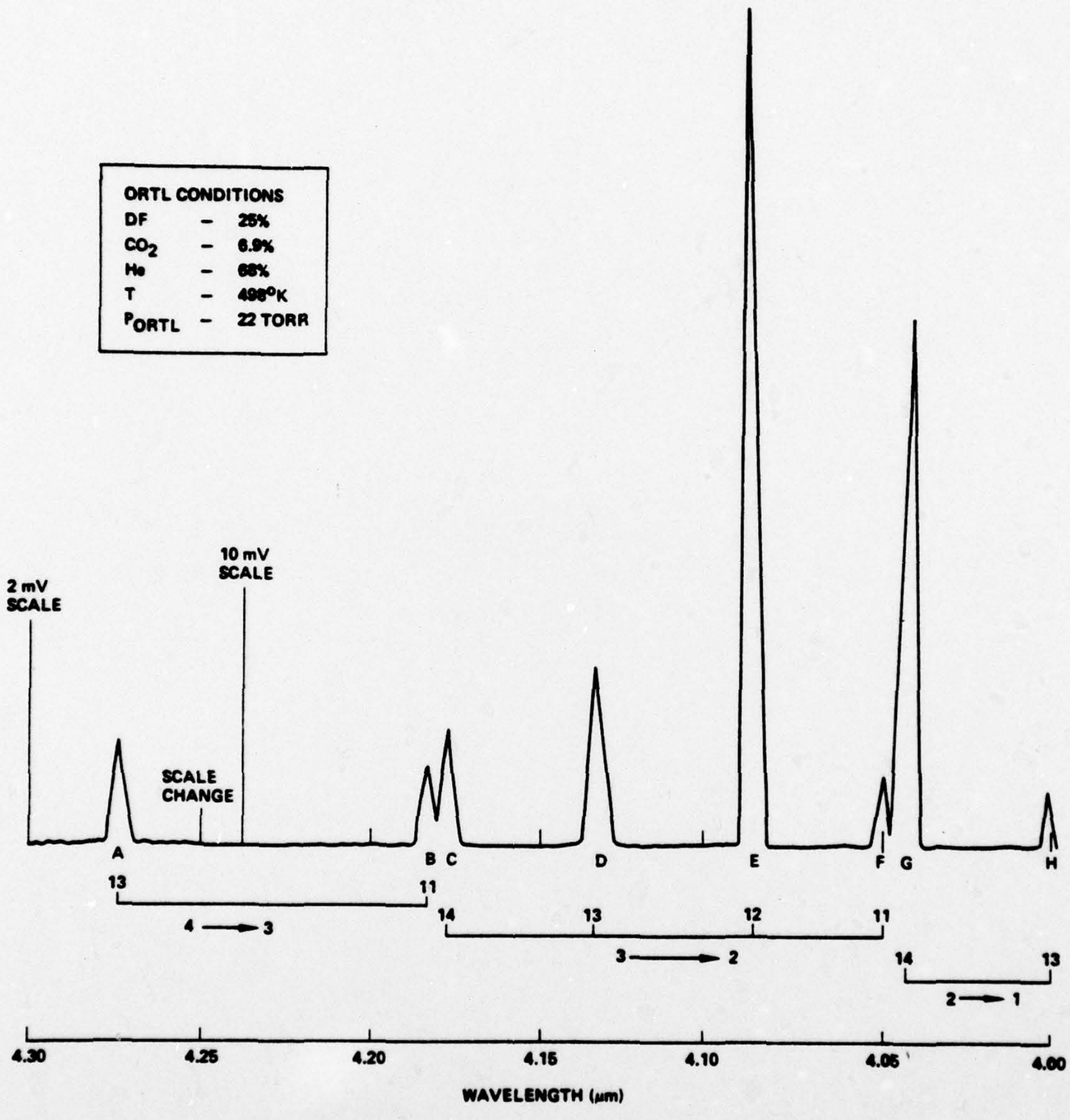

Figure 8. Optically Pumped DF Laser Spectroscopy.

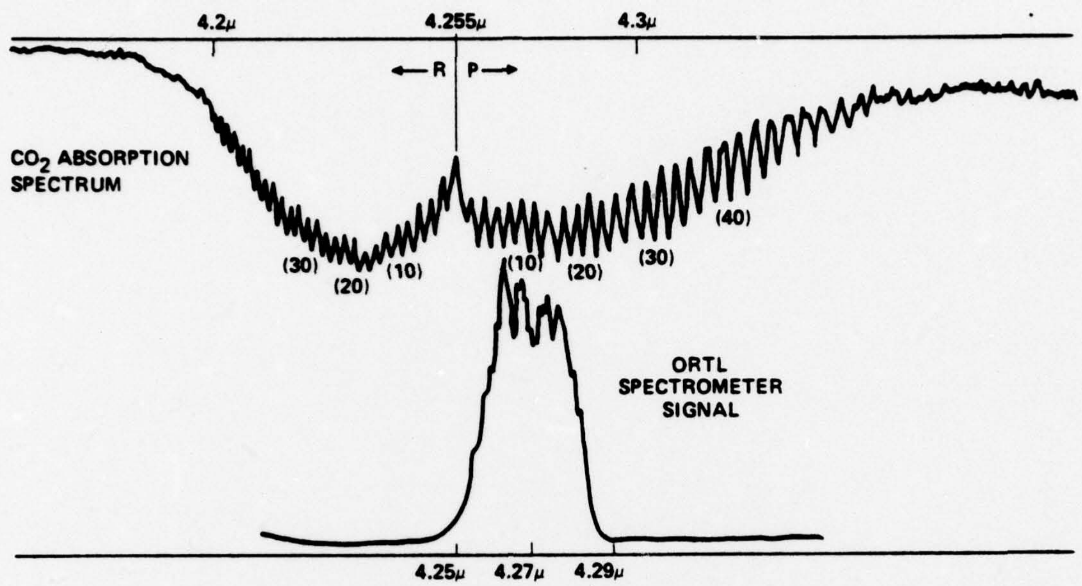

Figure 9. 4.3 μM Laser Spectroscopy.

and 10.6 μm radiometer filters gave the same modulated signal as spoiling the cavity. Therefore, 4.3 μm lasing and 10.6 μm lasing were not simultaneously occurring. From the peak radiometer signal, one can estimate the circulating flux inside the ORTL cavity. Recalling the radiometer calibration described in Section 2.1, the observed signal of 270 mV implies an intracavity power of 3.2 watts, and intracavity flux of 45 watts/cm^2. The total power absorbed by the gas can be calculated from the recorded temperature rise via the expression

$$W = 4.18\, \dot{Z}\, \Delta T \sum_i \beta_i\, C_{p_i}$$

where $\dot{Z}$ is the total molar flow rate through the ORTL nozzle, ΔT the observed temperature rise, β_i the mole fraction and C_{p_i} the heat capacity of the ith ORTL component. Substituting the values listed in Figure 7 yields 3.35 watts for the power absorbed by the gas.

Figures 8 and 9 show the spectrometer data. In Figure 8, the output in the region from 4.30 μm to 4.0 μm was examined with an instrument resolution of 2.3 cm^{-1}. Lines shorter than 4.2 μm cannot originate from

CO_2 ν_3 transitions; therefore they must be assigned to other transitions. The assignment is shown in Table II. (Literature values are obtained from R. E. Meredith and X. S. Kent, Line Strength Calculations, Willow Run Report, 1966.)

Except for the 4 → 3 transitions, the optically pumped DF ORTL lines overlap with the DF pump lines. However, not all pump lines are observed in the ORTL output. The signal originates from stimulated emission and is not scattering or fluorescence because it is modulated by the shutter. Although it seems surprising that DF lines should be excited to laser oscillation in a DF pumped laser, partial inversion and positive gain on higher J levels can be achieved by thermal redistribution from strongly pumped transitions.

TABLE II. DF LINE ASSIGNMENT

Peak	$\lambda_{Measured}$ (cm^{-1})	$\lambda_{Literature}$ (cm^{-1})	$\lvert\lambda_M - \lambda_L\rvert$ (cm^{-1})	Assignment V	J
A	2340	2339.7	0.3	4 → 3	P (13)
B	2391	2390.4	0.6	4 → 3	P (11)
C	2394	2393.2	0.8	3 → 2	P (14)
D	2419	2419.7	0.7	3 → 2	P (13)
E	2447	2445.9	1.1	3 → 2	P (12)
F	2471	2471.7	0.7	3 → 2	P (11)
G	2475	2474.2	0.8	2 → 1	P (14)
H	2500	2501.4	1.4	2 → 1	P (13)

Figure 9 shows the spectral scan in the 4.3 μm region. The upper trace is a CO_2 absorption spectrum taken by the same spectrometer with slits 70 μm wide (0.75 cm^{-1} resolution). The lower trace is the ORTL signal scanned from 4.2 μm to 4.5 μm with slits 1 mm wide (11.6 cm^{-1} resolution). The observed signal exhibits a number of local maxima which can be assigned to various CO_2 P-transitions as shown in Table III. (Literature values are taken from R. A. McClatchey, et al., AFCRL Atmospheric Absorption Line Parameters Compilation, AFCRL-TR-73-0096, January, 1973.) There is but one problem with the above assignment. The spectrometer resolution, being seven times larger than the spacing between adjacent CO_2 lines, was not expected to be capable of resolving rotational structure. An alternate hypothesis would have the observed spectrum be attributed to temporal oscillations of the DF $P_3(13)$ line at 4.274 μm. The belief that the observed radiation emanates from the CO_2 molecule, rather than the DF, is based on a number of observations. The observed signal corresponds to anticipated CO_2 transitions. Not only do the four larger maxima correspond to P(8), P(10), P(14), and P(16), but the smaller peaks on the short and long wavelength slopes correspond to the positions of P(2), P(4), P(6), P(18), and P(20). The reduction in signal in the region of P(12) may be associated with the near resonance with the P(13) $v = 4$ to $v = 3$ DF line. Furthermore, there were no temporal variations elsewhere on this trace nor on other spectra, including the one shown in Figure 8. The possibility that these unique signal variations are really temporal variations (in a DF line) with a period corresponding to the sweep time between CO_2 P-transitions is less likely. Furthermore, the shape of the observed signal is not consistent with a single laser line distorted by the slit function. This apparent discrepancy between the resolution exhibited by the spectrometer trace and the actual spectrometer slit settings has not been as yet resolved.

We have also examined the possibility that 4.3 μm transitions associated with combination levels of CO_2 may be responsible for the observed spectrum shown in Figure 9. Specifically, the line positions of CO_2 $(01^11) \rightarrow (01^10)$ and CO_2 $(00^02) \rightarrow (00^01)$ were calculated using spectroscopic constants tabulated by McClatchey, et al. For the $(01^11) \rightarrow (01^10)$ transition, the lines corresponding

TABLE III. CO_2 ORTL LINE ASSIGNMENT

$\lambda_{Measured}$ (cm^{-1})	$\lambda_{Literature}$ (cm^{-1})	Assignment $(00^01) \rightarrow (00^00)$
2346.9 ± 0.8	2347.58	P(2)
2345.4 ± 0.8	2345.99	P(4)
2344.0 ± 0.8	2344.35	P(6)
2343.1 ± 0.4	2342.73	P(8)
2340.7 ± 0.4	2341.06	P(10)
2337.5 ± 0.4	2337.66	P(14)
2335.9 ± 0.4	2335.92	P(16)
2334.3 ± 0.8	2334.16	P(18)
2333.4 ± 0.8	2332.37	P(20)

to the experimentally observed wavelengths include P_2 and R(2) through R(8); for the $(00^02) \rightarrow (00^01)$ transition, the lines R(14) through R(26) fall in the appropriate wavelength range. Both potential assignments could, however, be ruled out by the absence of correlated P-transitions. A spectrometer scan from 4.2 μm to 4.5 μm revealed no such radiation.

3. FUTURE WORK

Although laser oscillation has been achieved at 4.3 micrometers, there are still many unanswered questions. As an initial step, unequivocal confirmation of CO_2 4.3 μm oscillation is desired under various excitation conditions with outcoupled 4.3 μm laser radiation. Definitive proof of CO_2 4.3 μm oscillation can be obtained by sufficiently high resolution spectroscopy. It is likely that CO_2 laser performance can be improved by suppressing DF oscillation while allowing CO_2 oscillation. This could be achieved by either reducing high vibrational DF population densities or by the use of wavelength selective CO_2 resonators. The most practical wavelength selective resonator appears to be one which uses a Littrow mounted grating as one of the resonator elements. This grating would be designed to allow oscillation on one CO_2 P-transition only. The selected transition would be one which does not overlap a DF transition.

Once competing DF oscillations are suppressed, the characterization of the CO_2 ORTL performance can be pursued. Variation of DF pump flux intensity and wavelength distribution and variation of ORTL pressure, temperature, and gas mixture can be carried out in a controlled manner to enhance our understanding of the system and the physical processes involved. By carrying out this investigation in conjunction with a strong modelling effort the relative importance of various processes not included in present models can be assessed and a sound basis for performance prediction can be developed.

The other area for investigation involves questions of system efficiency, and apparatus design. There are a number of improvements to the present experimental configuration which should be made. The replacement of the Brewster window which separates the DF pump laser from the ORTL cell by a simplified aerodynamic window is expected to reduce system losses. Optimization of the design of the helium curtain confining the ORTL flow is another area in which improvements can be made. Because of the large pump flux levels that are required to reach the threshold for laser oscillation

in a two-level ORTL, measured efficiency tends to be low in a small device. High efficiencies are more easily achieved with scale-up, and a higher experimental value would be measured. Because the system characterization would also be much easier in a system which is well above threshold, an increase in DF pump power allowing a longer gain length ORTL cell to be used is extremely desirable.